A BW Risk Assessment
Historical and Technical Perspectives

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The use of pathogens and toxins as weapons is not new and is certainly not a creation of recent biotechnical advances. Documented use of biological weapons (BW) dates at least as far back as the Middle Ages, when plague-infected cadavers were catapulted over the city walls of Kaffa. However, it was not until the fall 2001 anthrax attacks along the East Coast of the United States that BW use—especially in the form of bioterrorism—was brought to the forefront of the U.S. national security debate. Unfortunately, the risk of BW use or bioterrorism is not well understood, and the rapid advances of and accessibility to biotechnology have only served to increase confusion. This article aims to provide a comprehensive assessment of the risk of the use of biological weapons by combining a historical overview of past BW activities with an analysis of the technical requirements necessary to develop and deploy such weapons.

BW risk assessments have often presented an argument based on either historical precedence of BW research, development, and use or the scientific and technical skills needed to transform a pathogen into a weapon. These different approaches have led to different conclusions. BW attacks that have occurred, particularly those perpetrated by terrorists, have been low-consequence events. Historical and security studies assessments generally conclude that states are the actors most likely to commit a high-consequence BW event, including a state-sponsored act of terrorism. Consequently, adherents to this perspective support strengthening multilateral initiatives—such as the Biological and Toxin Weapons Convention (BWC) and the Australia Group—aimed at eradicating state-based BW proliferation.[1]

By contrast, technical assessments tend to conclude that the risk of BW use by both state and nonstate actors is significant and growing rapidly because of biotechnology advances and the increased availability of dual-use materials and state-of-the-art biotechnologies. These assessments presume that any technical

advance that lowers the barrier to creating a high-consequence event enhances the risk. In general, technical assessments conclude that the only answer to the BW threat is in improving surveillance, detection, diagnostics, vaccines, and therapies—in other words, strengthening preparedness to respond to an intentionally introduced infectious disease.[2]

Risk is a function of probability and consequences. In other words, higher risk can be a result of an increase in probability that an event will take place or an increase in the severity of the consequences if the event were to occur. For this analysis, risk varies with (1) the likelihood of an attack with a biological weapon being executed and (2) the severity of the consequences of that attack. This paper argues that historical events and technical factors affect both of these components of risk, and both must be examined to achieve a comprehensive risk assessment.[3] This combined approach to assess the risk of BW use can help guide policymakers in defining a coherent biodefense and BW nonproliferation strategy.

For the purposes of this analysis, a "high-consequence BW event" is one that results in mass casualties, and a "low-consequence BW event" is one that causes few casualties. A high-consequence BW event would severely affect national or international public health, safety, the economy, or security, while a low-consequence BW event would not. A premise underlying this distinction is that few biological agents and a limited number of dissemination methods are available to cause a high-consequence event, but a variety of attack methods and a wide range of agents could be employed to generate a low-consequence event. These definitions are extremely broad and exclude consideration of the economic and social consequences that inevitably would accompany the use of a biological weapon. However, despite this limitation, these general categories can be analytically useful.

Based on this method of risk analysis, this article concludes that the risk of biocrimes by lone actors and biological warfare by well-developed states is low; the risk of biological warfare by rogue states is low to moderate; and the risk of bioterrorism by nonstate actors is low to moderate but increasing over time.

HISTORY OF BW DEVELOPMENT, POSSESSION, AND USE

The historical record of biological weapons development and deployment is likely rife with holes that will never be filled. The past is often obfuscated by circumstantial evidence, conflicting reports, or the absence of documentation. Additionally, numerous technical factors may impede the verification of alleged BW attacks. For example, suspected BW use may actually have been a naturally occurring disease outbreak. Further, natural outbreaks may be used as a screen for actual BW attacks.[4] Thus, if a perpetrator never claims responsibility, an incident may never be discovered. Nevertheless, a study into the history of BW development and use, however lacking, can cast light on developing trends in

BW proliferation and use and can provide a baseline for evaluating the likelihood and consequences of future BW events. This section examines the incidents of BW use at both the state and nonstate levels and is organized into two chronological periods: before the 1972 opening of the BWC and after. The treaty, which has been ratified by 151 member states, bans the development and production of biological weapons and is considered the seminal document in controlling state-based BW proliferation.

State BW Programs and Use Before the BWC

Prior to the development of modern warfare—in which states apply new scientific developments to deploy tanks, machine guns, and aircraft—victory depended largely on the number of men fighting for each side. Wars were typically wars of attrition, and incapacitating soldiers or disrupting supply lines could result in the decisive numerical advantage necessary for victory.[5] Some of the earliest reports of BW use reflect this need to incapacitate or kill enemy combatants. For example, in the Middle Ages, cadavers infected with plague were catapulted over city walls. Later, in the American colonial period, the British distributed smallpox-infected blankets to Native Americans.[6]

The dawning of the 20th Century opened a new chapter in the history of biological warfare. States, especially in Europe, began to explore the strategic and tactical roles of unconventional weaponry, including biological and chemical weapons. By World War I (WWI), France and Germany both had active, if rudimentary, BW programs. These programs can be best described as unsophisticated sabotage programs that targeted the beasts of burden and food products required to wage war. Dissemination methods were generally crude. The German program, which was likely initiated in response to intelligence about France's active BW program and suspected Russian efforts, involved infecting food sources for animals, brushing bacteria on the noses of animals, and directly "jabbing" infected implements into animals that would be shipped to the front for use by the Allied powers.[7] The overall success of these efforts is difficult to assess. Although there were epidemics of glanders (*Burkholderia mallei*) among livestock controlled by the Allied powers in Europe, this disease is endemic in the region, and Germany never claimed responsibility. Both the German and French programs studied glanders to infect livestock.

Mostly in response to intelligence of past and current French and German BW activities, state-based biological weapons programs were established in Canada, Great Britain, Japan, the Soviet Union, and the United States during the 1920s and 1930s. These programs were initiated despite the Geneva Protocol of 1925, which outlawed chemical and biological methods of warfare; it did not preclude research and development. Many signatories, such as Britain and the

Soviet Union, reserved the right to use biological weapons against any state not party to the protocol or any state in violation of the protocol.[8]

France and Germany continued research and development into biological weapons after WWI. In the early 1920s, France conducted experiments that examined whether pathogens could be effectively delivered by explosive devices. Animal experiments during this time used typhoid fever (*Salmonella typhi),* pneumonia *(Streptococcus pneumoniae),* and cholera (*Vibreo cholerae).* In general, France's interwar BW program was limited in scope and defensive in nature and only became more extensive in reaction to Germany's 1934 withdrawal from the Geneva Protocol. At this time, France accelerated its BW development and initiated a cooperative Anglo-French research program.

Although Germany pursued an offensive BW capability in WWI, Adolf Hitler, who rose to power in 1932, opposed biological warfare even as a tool of retaliation. Instead, Hitler directed research toward defensive measures in the event of a BW attack by an Allied power. During World War II, Germany performed experiments with diseases—including epidemic typhus (*Rickettsia prowazekii and Rickettsia mooseri*), the hepatitis A virus, and malaria (*Plasmodia* spp.)—on prisoners in concentration camps. The purpose of these experiments was to aid in the development of preventive vaccines.[9]

The defeat of Imperial Russia in WWI, particularly the scores of casualties suffered on the Eastern Front, influenced the initial development of the new Soviet military. Determined not to endure such a defeat again, the Soviet Union began to create a modern military with all manner of armaments at its disposal. While the intent was originally to develop only chemical weapons, Soviet unconventional arms programs evolved to include biological weapons as well.[10] From the late 1920s, the Soviet BW program developed under military control and direction. After conducting successful experiments with anthrax and botulinum toxin, the military persuaded Soviet policymakers that specifically modified bombs could effectively deliver pathogens to enemy territory. As a result, the Soviet Union decided to expand the scope of research to include both offensive and defensive elements. Early offensive research focused on a variety of pathogens, including *Bacillus anthracis*, *Clostridium botulinum*, *Yersinia pestis*, and *Mycobacterium tuberculosis*—the causative agents of anthrax, botulism, plague, and tuberculosis, respectively. Field tests, including open-air dissemination of these agents, were conducted on animals at numerous sites in Kazakhstan and Uzbekistan. Eventually, Vozrozhdeniye (or Rebirth) Island in the Aral Sea became a primary outdoor BW testing ground.[11]

Following the January 1941 publication of an article in *Informatsionni Sbornick* (a semi-official government bulletin) detailing BW work in other nations, Soviet officials became alarmed at their nation's general lack of preparedness against a BW attack. An acceleration of the Soviet program resulted and included experiments on prisoners near Ulan Bator (Mongolia), in Leningrad, in the White

Sea off the Kola Peninsula, and on one of the Solovki Islands. These human experiments may have caused a plague epidemic in Mongolia that resulted in 3,000 to 5,000 deaths, after a prisoner escaped who had been the subject of a BW experiment.[12]

However, the priority placed on BW development within the larger context of military operations is unknown. Of particular interest is an allegation that the Soviet army used biological weapons against the German army in 1942. That year, the Soviet BW program relocated to Kirov (560 miles northwest of Moscow) to escape advancing German troops. During the 1942 battle of Stalingrad, tularemia (*Francisella tularensis)* infected German army troops in southern Russia. That outbreak eventually crossed battle lines and befell Soviet troops as well. In addition, in 1943 an outbreak of Q fever was reported in the Crimea. Suspiciously, both diseases were under research by the Soviets for possible weapons application, but whether these incidents resulted from BW use remains unconfirmed.[13]

Imperial Japan's BW work was the most egregious of the many interwar and WWII-era state programs. Starting as a defensive program in 1931 under the command of Army major Dr. Shiro Ishii, Japan's program quickly evolved into an offensive program following the invasion and occupation of Chinese Manchuria in 1932. It was here in Manchuria where Dr. Ishii and others conducted extensive human testing associated with Japan's BW research and development program. Japan continued and expanded its biological weapons program until the end of WWII.

Historically identified as Unit 731, the Japanese BW program researched, usually via human experimentation, the weaponization capabilities of plague, anthrax, cholera, typhoid, and glanders, among other infectious disease-causing microorganisms.[14] The majority of the research conducted with these biological agents occurred within prison camps scattered throughout occupied Manchuria. Although exact figures are not available, it is estimated that between 3,000 and 20,000 Chinese and Chinese-based ex-patriot Soviet prisoners died as a result of Unit 731's biological warfare research activities.[15]

Unit 731 also conducted extensive biological warfare against Chinese soldiers and the civilian population during WWII. Typically, Japan used rudimentary dissemination techniques to spread disease, including poisoning wells and rivers with cholera, dropping agent-filled ceramic "bombs" over targets, and introducing plague-infected fleas and rats into Chinese cities and towns. Again, exact details are ambiguous, but recent estimates have calculated BW-related deaths in China to be up to 580,000, including two separate cholera attacks, each of which may have killed more than 200,000 people.[16]

The British BW program began as a cooperative defensive program with France in 1936. It evolved into an offensive and defensive program in the 1940s but returned to a strictly defensive program by the 1950s. Britain's rationale for de-

veloping biological weapons, as was often the case in this period, rested partly on concerns that other nations—most notably, Germany and the Soviet Union—had similar programs.[17] During the interwar years, the British program focused primarily on countermeasures to be employed against anthrax and botulinum toxin biological weapons, including vaccines and therapies for both humans and animals.[18]

The British work on anthrax involved various dissemination techniques, including aerosolization. In 1942, British researchers from Porton Downe converged on Scotland's Gruinard Island to conduct tests on sheep to study the feasibility of anthrax dissemination from traditional bombs. The British also infected "cattle cakes" with anthrax as part of an anti-livestock research program. These cakes, which contained *Bacillus anthracis* spores, were to be dropped from bombers over livestock pastures in hopes of disrupting German food production capabilities. However, British policy dictated that the cakes be deployed only in retaliation against a German BW attack. In the end, all but a few of the approximately 5 million cattle cakes were destroyed after WWII.[19] Despite their extensive testing, the British never deployed biological weapons against the Axis powers.

After the Second World War, the United Kingdom expanded its BW research to other diseases, such as tularemia, brucellosis, plague, and Venezuelan equine encephalitis. Until 1955, these agents were tested at sea using a variety of dissemination devices. In 1958, the chiefs of staff stated that neither biological nor chemical weapons had strategic value. By this time, the United Kingdom had informed its partners, Canada and the United States, that it would engage only in defensive BW research.[20]

Canadian BW research facilities were developed at Goss Isle and Suffield during the war. Initially, Canadian officials feared the consequences of possible enemy sabotage against its population. Of particular concern was an outbreak of either bubonic plague or rinderpest, a devastating cattle disease. Canada began its collaboration with the United States by sharing work on *Aegis aegypti*, a species of mosquito that is the vector for both yellow fever and malaria. In return, Canada was given access to U.S. work on botulinum toxin, malaria, plague, typhus, and other diseases.

In 1941, Canadian, American, and British scientists met in Ottawa to discuss the nature of the BW threat and, more specifically, the pathogens that were thought most likely to be used by Germany and Japan. Formal cooperation among the three nations began in 1942, including collaboration with Britain's anthrax program and a joint initiative to develop a rinderpest vaccine. The Canadian-U.S. research collaboration expanded to plague, brucellosis, and botulinum toxin, emphasizing the use of insects as vectors. Continued collaboration resulted in the development of an especially lethal strain of botulinum toxin. Despite their coordinated efforts, the United States, United Kingdom, and Canada theoretically could not deploy anthrax as a weapon until the end of the war. Canada

continued its partnership with the United States and the United Kingdom after the war and through the early years of the Cold War.[21]

Although the United States, like Japan, was not party to the Geneva Protocol, it did not pursue BW research and development until WWII. As early as 1926, the chief of the U.S. Chemical Warfare Service concluded that there was no effective method for disseminating "germs" in warfare. This belief was strengthened by a 1933 Army Medical Corps article, which claimed that successful dissemination of a BW agent would prove extremely difficult. This U.S. opinion began to change in 1939 with scattered reports about other state BW programs. Although some U.S. officials remained skeptical about the need for a BW program, the War Bureau of Consultants concluded in 1942 that warfare using biological weapons was feasible and posed a threat to U.S. national security. President Roosevelt then agreed to initiate a defensive BW program that utilized both governmental and private academic resources, including those of other allied nations.

The Americans, who cooperated closely with British and Canadian scientists and military personnel during WWII, created a vast BW research and development network throughout the United States. The U.S. program was headquartered in Camp Detrick (now Fort Detrick), Maryland, and included testing grounds in Mississippi and Utah; a large production facility in Terra Haute, Indiana; and research space at universities such as Harvard and Stanford.[22]

The U.S. BW program was officially limited to retaliatory use only, but this fact did not prevent the production of vast amounts of biological materials. The United States stockpiled anthrax, botulinum toxin, tularemia, glanders, and a variety of anti-plant agents, including rice blast fungi, which could be used to damage Japan's most abundant and important crop. Anti-plant agents were considered an ideal weapon because they produced no adverse effects on humans.[23]

After WWII, the United States scaled back its BW research programs, and the production facility in Indiana was closed. However, the United States later opened a new facility in Pine Bluff, Arkansas, reflecting an expansion of the program during the Korean War (1950-1953). It was at this time that U.S. technological advances allowed for large-scale fermentation and weaponization of pathogens and toxins. In addition, the United States also conducted research to develop medical countermeasures to protect U.S. troops from a BW attack.[24]

During the 1960s, the U.S. program expanded its arsenal of biological weapons to include anthrax, botulinum toxin, tularemia, brucellosis (*Brucella suis*), Q fever, staphylococcal enterotoxin B, Venezuelan equine encephalitis, rice blast, rye stem rust, and wheat stem rust.[25] The U.S. offensive program was terminated by President Nixon in 1969 in anticipation of U.S. entry into compliance with the BWC. The United States also adopted a "no-first-use" policy in relation to biological weapons.[26] Table 1 presents a summary of these state programs (confirmed and alleged), their years of operation, and the types of activities they explored prior to the adoption of the BWC.

State BW Programs and Use after the BWC

The BWC opened for signature in 1972 and entered into force in 1975. The convention was the first multilateral treaty to ban an entire weapons system from the research stage to development. Although the BWC does not specifically prohibit the use of biological weapons, the treaty's provisions make their deployment unambiguously illegal. By the time the treaty was drafted, many efforts were under way to prevent offensive BW research and stockpiling; for instance, the United States had renounced biological warfare in 1969. Despite America's good-faith entry into the BWC, however, not all states followed the same course.

In 1973, less than one year after signing the BWC, the Soviet Union began the formulation of a new and significantly larger BW program under the aegis of Biopreparat, an established civilian pharmaceutical conglomerate. U.S. intelligence did not comprehend the enormity of the Soviet program until it was revealed by two high-level defectors, Vladimir Pasechnic (director of The All Union Scientific Research Institute of Ultra Pure Biopreparations) in 1989 and Kanadjan Alibekov (senior deputy director of Biopreparat) in 1992.

At its height, the Soviet Union's BW program, which was divided between Biopreparat and Ministry of Defense operations, employed more than 60,000 workers, operated at least 55 facilities, and had a monthly agent production capability measured in the hundreds of tons.[27] The Soviet program focused on both "operational" and "strategic" biological weapons. Operational weapons, such as tularemia, glanders, and Venezuelan equine encephalomyelitis, were mainly incapacitating agents and were to be used against targets along the battlefront or directly behind enemy lines. Anthrax, plague, smallpox, and Marburg were to be used as strategic weapons against enemy population centers.[28] Other agents successfully weaponized within Biopreparat included those that cause Q fever, brucellosis, and the nonhuman diseases psittacosis (fowl), rinderpest (cattle), African swine fever, wheat stem rust, and rice blast.

Biopreparat focused on all aspects of BW research, development, production, and deployment. This wide mandate included developing large-scale manufacturing and testing techniques; building improved dissemination technologies, including aerosol sprayers and warhead delivery systems; creating more virulent, infectious, and contagious pathogens by means of genetic engineering and antibiotic resistance experiments; and transforming nonpathogenic microorganisms into lethal agents.[29] But this massive clandestine weapons program began to weaken during the late 1980s and early 1990s and was disclosed and downsized considerably following the 1991 dissolution of the Soviet Union. In 1992, Russian President Boris Yeltsin signed a memorandum prohibiting all BW-related activity.

Despite President Yeltsin's 1992 declaration, there remains doubt within the international community about Russia's commitment to abstaining from offen-

Table 1
Summary of State Programs before the BWC Entered into Force (1975)

State	Year	Types of Activities
Germany	1914-1945 (sporadic)	R&D and deployment
France	1914-1941 (sporadic)	R&D and possible deployment
Japan	~1918-1945	R&D, production, and deployment
Soviet Union	1920s-1975	R&D, production, and possible deployment
United Kingdom	1936-1969	R&D and production
Canada	post-WWI-1969	R&D and production
United States	1942-1969	R&D and production

sive BW research and production.[30] In 2003, Assistant U.S. Secretary for Verification and Compliance Paula A. DeSutter said that the United States "believe[s], based on available evidence, that Russia continues to maintain an offensive BW program in violation of the Biological and Toxin Weapons Convention."[31]

Iraq also chose to ignore the BWC prohibitions and is believed to have begun its program in either the mid-1970s or early 1980s.[32] Prior to the Gulf War in 1991, U.S. military intelligence confirmed that Iraq, a signatory to the BWC, was developing both *Bacillus anthracis* and botulinum toxin for use in biological weapons. In addition, the Iraqi program worked with cholera, plague, *Salmonella* spp., ricin, aflatoxins, haemorrhagic conjunctivitis virus, staphylococcal enterotoxins, and camel pox.[33] By the time of the Iraqi invasion of Kuwait in 1991, Saddam Hussein had ordered an acceleration of Iraq's biological weapons program, including the loading of weaponized biological agents onto Al-Hussein (SCUD) missiles and aerial bombs. Many experts suggest that the chief reason these missiles were not deployed in the 1991 Gulf War was President Bush's threat of nuclear retaliation in the event of biological attack.[34] Following the 2003 invasion of Iraq, coalition forces organized a massive effort to locate evidence of an Iraqi BW program. To date, no BW stockpiles have been found and no conclusive evidence of a post-1991 Iraqi BW program has been established. But, according to David Kay, former head of the Iraq Survey Group, evidence of a post-1991 BW program would be almost impossible to discover and should not be completely ruled out.[35]

During the 1980s, South Africa developed a limited but nonetheless significant BW program, which it named Project Coast and, later, Project Jota. In contrast to the programs discussed above, which focused on widescale biological warfare, Project Coast was designed primarily for the assassination of anti-apartheid activists. Similar to the Soviet Biopreparat program, Project Coast was operated under the cover of the civilian biotechnical firm of Roodeplaat Research Laboratories (RRL).[36] At the RRL facilities north of Pretoria, South African government scientists researched and produced stocks of the microorganisms that cause anthrax, cholera, plague, and salmonella, as well as botulism and other toxins. Project Coast also placed a priority on genetic engineering and antibiotic resistance.

In 1993, South African President F.W. de Klerk ordered the dismantlement of Project Coast and the destruction of all biological and toxin agents, but recent events have cast doubt on the effect of those orders. According to the *Washington Post*, former South African bioweaponeer Daan Goosen contacted the Federal Bureau of Investigation with an offer to sell a genetically modified and weaponized pathogen sample for $5 million.[37] This episode, along with unsubstantiated rumors that high-level Project Coast personnel may have aided a Libyan BW program, highlights the difficulties inherent in BW disarmament. First, because biological materials are easily hidden or diverted, their destruction proves nearly impossible to verify. Second, qualified technical experts involved in the weapons program may find themselves suddenly unemployed and willing to provide assistance to "rogue regimes" or terrorist groups.

Bulgaria was also believed to have had a BW program intended primarily for assassination. In 1978, Bulgarian dissident Georgi Markov was killed in England after being injected with a tiny metallic sphere that contained ricin. An attack in 1978 against another dissident, Vladimir Kostov, also involved ricin. Mr. Kostov, however, survived the attack.[38] Bulgaria is currently a state party to the BWC.

Other states suspected by the U.S. Central Intelligence Agency of currently developing biological weapons or continuing to hold an interest in developing them include China, Iran, North Korea, and Syria.[39] Sudan and Cuba have also been suspected of pursuing biological weapons research.[40] Other states that, according to the open literature but unconfirmed by the U.S. intelligence agencies, may have a biological weapons program include Israel, Taiwan, and Egypt.[41] Table 2 presents a summary of post-BWC state programs (confirmed and alleged), their years of operation, and the types of activities that they explored.

Nonstate Actors and Biological Weapons

Nonstate actors are individuals or groups that act outside of a nation state's governing institutions. The threat of a nonstate actor using a biological weapon in terrorism is a primary concern of the United States. While the United States

Table 2
Summary of State Programs after the BWC Entered into Force

State	Year	Types of Activities
Soviet Union/Former Soviet Union	1975-present	R&D, production, and possible deployment
Iraq	1980s-(2003)?	R&D and production
Iran	? (intensified in 1995)-present	R&D
China	1950s–present	R&D
Syria	?-present	R&D
Libya	?-present	R&D
India	?-present	R&D
Pakistan	?-present	R&D
North Korea	1960s-present	R&D and possible production
South Africa	?-1994	R&D, production, and possible deployment
Sudan	?-present (?)	R&D
Israel	?-present	R&D
Taiwan	?-present	R&D
Egypt	?-present	R&D

has for many years been aware of the threat posed by bioterrorism, the fall 2001 anthrax attacks refocused attention on the issue and prompted enhanced biodefense efforts. This section explores the pattern of bioterrorism incidents, pathogen possession, attempted pathogen acquisition, and incidents of pathogen diversion. Bioterrorist acts discussed in this section are limited to the same time period as the previous section (1900-present). Unless otherwise noted, reported incidents come from the Monterey Institute of International Studies (MIIS) terrorism database. [42]

The earliest reported incident of bioterrorism within this time period occurred in 1910. The Pancho Villa guerillas, a nationalist-separatist group combating Mexican federal troops during the Mexican Revolution, cultured botulinum toxin by placing cooked green beans in sealed canisters. Rotting pork was added to the beans one week later. The mixture was then buried until the canteens swelled, thus indicating that the toxin was ready for use. Children dipped pottery

shards or obsidian into the mixture and threw the shards at federal sentries. No report exists on the overall effectiveness of this method of attack.

The first incident of bioterrorism conducted by a nonstate actor on an agricultural target within the studied time period occurred in Kenya in 1952. A nationalist-separatist group called the Mau Mau used African milk brush as a toxin against livestock. The Mau Mau cut incisions into the skin of 33 steers and put the latex of the plant directly into the wounds. Although eight steers died, the attack had little impact on the Kenyan government and did not help the Mau Mau achieve their goal of independence.[43]

In 1981, members of Dark Harvest, an environmental extremist group, delivered a package to a political party conference in the United Kingdom that contained *Bacillus anthracis*-contaminated soil from Scotland's Gruinard Island where extensive WWII anthrax testing had occurred.[44] The group intended to return the "seeds of death" to their sources.[45] No injuries resulted from this attack.

The first incident of bioterrorism in the United States occurred during the summer of 1984. On six separate occasions, the Rajneeshee religious cult deliberately contaminated salad bars with salmonella bacteria in The Dalles, Oregon.[46] They attempted to influence the outcome of local elections by keeping other members of the county away from the polling places on election day. The group purchased the salmonella seed stock from Seattle-based medical supplier VWR Scientific and cultured the bacteria using its own well-equipped laboratory and university-trained microbiologists. The Rajneeshee attacks caused 776 cases of food poisoning, some quite serious, but none resulted in death. The malicious nature of the event went unnoticed until a Rajneeshee cult member confessed after being arrested on unrelated charges over a year after the event.[47] Although the Rajneeshees failed to achieve their ultimate goal of winning the election and gaining political control of the town, they successfully caused many illnesses.

In the early 1990s, the Japanese religious cult Aum Shinrikyo, or Supreme Truth, made several attempts at bioterrorism. Although the cult is best known for successfully disseminating sarin gas in the Tokyo subway in 1995, its work with biological weapons provides an interesting case study. Aum Shinrikyo was led by the charismatic leader Shoko Asahara, who had an apocalyptic vision for a new world where he would be supreme leader. By the early 1990s, the cult had developed an extensive BW capability to carry out its doomsday agenda. Aum Shinrikyo's well-funded biological and chemical weapons program had a cadre of university and graduate-level trained microbiologists, who created high-tech biotechnology facilities where they worked undetected for four years. Their first targets, in April 1990, were the U.S. Navy bases at Yokohama and Yokosuka, the Narita airport, the Imperial Palace, and the Japanese Diet. The group attempted to disseminate botulinum toxin in the form of mist sprayed from a truck. This attempt failed for unknown reasons. Investigators suspect that the group may have used a weak strain of the toxin.[48]

Six subsequent Aum attacks occurred in 1993, all of which failed. The first of these attacks in June 1993 used botulinum toxin directed at guests of the wedding of Prince Naruhito. Similar to the previous attack, the group sprayed a mist of the toxin from a car. By the time of the second attack, July 1993, the group had switched to *Bacillus anthracis*. Aum Shinrikyo attempted to spray anthrax spores from the top of its Kameido compound in Tokyo. Three more attacks attempted in July 1993 were aimed at civilians in Tokyo, including two disseminations of the bacteria from moving vehicles and one from the roof of its compound. The key factor in Aum Shinrikyo's failure was that they used a vaccine strain of *anthracis*.[49] The last incident occurred in March 1995, when the group again attempted to disseminate botulinum toxin from three briefcases equipped with spraying devices. This attempt failed because the cult member responsible for placing the briefcases changed his mind and replaced the toxin with water. The lack of success by Aum Shinrikyo presents a puzzle for analysts: The cult invested significant resources in a well-equipped laboratory and had many well-trained scientists, but it still was not able to perpetrate a bioterrorist attack. Although an insider sabotaged the last incident, there is no widely accepted explanation for the other failures.

Another attempted bioterror incident took place in Tajikistan in 1995 and involved an Afghani warlord's acquisition of hepatitis virus from a local hospital. He subsequently sold infected fruit to Russian troops in Tajikistan as part of an effort to aid nationalist-separatist movements in Tajikistan. Notably, a small number of subsequent hepatitis illnesses developed among Russian troops during this same time period.

The most recent biological attack occurred in the fall of 2001, shortly after the September 11, 2001, terrorist events in the United States. The perpetrator(s) sent letters that contained weaponized anthrax to journalists and policymakers via the U.S. Postal Service.[50] Following these attacks, 11 inhalation and 11 cutaneous (7 confirmed and 4 suspected) cases of anthrax were identified in the United States. Five persons died after contracting the inhalation form of the disease.[51] Prior to these incidents, no U.S. citizen was known to have died from bioterrorism within the United States.[52] Approximately 10,000 individuals were potentially exposed to the bacteria, and treatment consisting of at least 60 days of post-exposure antibiotic prophylaxis was recommended.[53] In addition, many government and public buildings were shut down because of evidence of contamination. As of this writing, the perpetrator(s) remain unknown. Consequently, specific motivations and/or group identity (if applicable) are also unknown. Finally, although investigators have identified the strain of anthrax that was used (the Ames strain), it is unknown whether this strain was acquired by theft from a laboratory or was isolated from nature.

In addition to actual bioterrorism incidents, MIIS has identified several cases in which individual(s) had unauthorized possession of pathogens but did not de-

ploy them as weapons. Whether or not these individuals would have deployed these pathogens remains unclear. However, possession remains an important component of understanding the threat of BW use.

Of the numerous examples of possession without use, the most famous incident is that of Larry Wayne Harris. In 1995, Harris ordered three vials of *Yersinia pestis*, the causal agent of plague, from the American Type Culture Collection (ATCC). Following the shipment, ATCC became suspicious of Harris and notified the Centers for Disease Control and Prevention (CDC). A search of Harris's property in 1997 discovered the three vials, which were still in their original containers.[54] A further search of his home found explosives and material indicating that Harris was a member of Aryan Nation, a right-wing, white supremacist organization. Because it was not illegal to possess human pathogens, Harris was arrested for obtaining the bacteria through falsified documents. Harris claimed that he was researching the pathogen to counter what he believed was a threat from Saddam Hussein to release "super-germ-carrying rats" in the United States. Harris was subsequently convicted of fraud by wire in 1997.

Also in 1995, Thomas Leahy was discovered to have constructed a makeshift ricin laboratory in his basement after authorities arrested him for shooting his stepson in the face. Mr. Leahy pleaded guilty to a violation of the Biological Weapons Anti-Terrorism Statute and was sentenced to 12 years in federal prison.

Summary of Historical Use of Biological Weapons

Historically, states have been responsible for most BW proliferation but, for a variety of reasons, have rarely used the weapons that they have produced. First, states have generally viewed biological weapons as tactical, not strategic, weapons. Indeed, only the massive Soviet program developed plans to use biological agents as strategic weapons, yet it remains unclear whether the Soviet Union ever achieved that capability. Second, biological weapons tend to be imprecise and ineffective in war. Third, states feared their use would engender overwhelming reprisal. Finally, the post-WWII era of nonproliferation spawned an attitude of disapproval toward the use of biological weapons, as evidenced by the BWC. Because biological weapons were seen as increasingly unattractive and immoral, many states chose to relinquish their programs. Thus, based on the historical record, the probability of BW use is considered very low for well-developed states and low for rogue states.

The historical record of bioterrorism incidents demonstrates two broad patterns of biological agent acquisition and BW use: (1) nonstate actors appear to be more willing than states to use pathogens and toxins maliciously, and (2) nonstate actors are inclined to use pathogens and toxins that are readily available. While the frequency of bioterrorism incidents seems to be increasing, high-consequence attacks have not been a part of this rising trend. This does not mean that groups will not try to obtain high-risk pathogens and toxins (HRPTs).[55]

The cases of Aum Shinrikyo and the anthrax attacks of fall 2001 indicate that there may be individuals or groups who are willing and able to use HRPTs. However, the Rajneeshee attack underscores another important element of bioterrorism: Different nonstate actors may pursue bioterrorism for different ends and with different motivations. The Rajneeshees and the perpetrator(s) of the anthrax attacks intended to conceal their use of bioterrorism. By contrast, other nonstate actors have claimed responsibility for their actions. This fact highlights the importance of understanding the motivations of various groups who may be pursuing bioterrorism.

In assessing the likelihood of bioterror attacks, it is necessary to ask whether biological weapons are the weapons of choice for terrorists. The vast majority of terrorist incidents have involved conventional means of attack, such as the use of guns, hijackings, and vehicle and suicide bombs. Conventional weapons are inexpensive, readily available, relatively easy to use, and highly dependable, predictable, and effective. Some scholars also cite the following self-imposed constraints on bioterrorist groups: (1) the difficulty in coordinating and carrying out the logistics and other organizational hurdles for larger or more technologically complex operations (e.g., the Aum Shinrikyo attempts); (2) the desire for inducing terror or inconvenience but *not* mass deaths (e.g., the Rajneeshee salmonella poisoning); and (3) the desire not to alienate their members or supporters.[56] Furthermore, terrorists may prefer the instant gratification obtained from using explosives and other conventional weapons. Not only is the effect of a biological weapon delayed, but terrorists may also believe that they will have more control over, and more confidence in, a conventional weapon's effectiveness. Finally, the recent examples of terrorist attacks directed against the United States (e.g., September 11, 2001; the *USS Cole*; the African embassies; and the Murrah Federal Building) demonstrate a desire to use asymmetrical means to inflict highly symbolic (and emotional) damage.

In the past, nonstate actors, lacking the resources available to nation states, have not had the capacity to develop biological weapons that could cause high consequences. Nonetheless, nonstate actors have on numerous occasions used biological weapons to cause low-consequence events. In contrast to states, nonstate use of biological weapons has not been confined to war. Issues such as protecting civilian populations, adhering to international norms of behavior, and fear of attribution have not been disincentives to use. Although there remains a low to moderate probability that nonstate actors would use biological weapons, the historical record shows that the consequences of such use would be low to moderate.

Terrorism analysts in the 1990s noted a new form of terrorism emerging, one that was more lethal, indiscriminate, and complex, involving new adversaries, motivations, and methods.[57] The events of September 11, 2001, as well as the anthrax attacks in the United States, have underscored the concern over

whether incidents of bioterrorism will increase in the future and whether these incidents will have catastrophic consequences. These questions remain unanswered. Many scholars have suggested that rapid advances in bioengineering and biotechnology, growth in the number of high-containment facilities worldwide, consolidation in U.S. and international agricultural business, the inadequacies of basic public health infrastructure, and a fundamental weakness in biological arms control will persuade states and nonstate actors to pursue bioterrorism and BW proliferation.[58] In order to evaluate this hypothesis that high-consequence BW use is becoming more probable—that the risk is increasing—it is important to evaluate the technical hurdles a would-be bioterrorist would have to overcome to perpetrate a successful bioterrorism event.

TECHNICAL HURDLES TO SUCCESSFUL BW DEPLOYMENT

Creating and deploying biological weapons are not trivial tasks, as several technical hurdles need to be navigated: (1) acquisition of a virulent pathogen or toxin; (2) production of the agent in suitable form and quantity; and (3) effective dissemination of the agent.[59] Specific knowledge, skills, and equipment are necessary to overcome these technical impediments.

Acquisition of a Virulent Agent

The first step in creating a biological weapon is the acquisition of a virulent pathogen or toxin. While this may seem obvious, the process can be complicated. Some experts even claim that the acquisition of a virulent strain is the rate-limiting step.[60] For example, Aum Shinrikyo was unable to obtain a virulent strain of anthrax. Although strains of a particular pathogen may be immunologically similar, they can vary widely in terms of pathogenicity, lethality, transmission rates, environmental susceptibility, and other factors. The ability to identify correctly whether a particular pathogen strain is virulent or avirulent is a necessary technical skill.

Most pathogens and toxins are available from a variety of sources. The first possible source is nature. Human, animal, and plant disease outbreaks occur naturally throughout the world, and these outbreaks are generally reported in a variety of trade and news publications, as well as Internet disease surveillance systems such as ProMED.[61] Consequently, a bioweaponeer could visit an outbreak location and collect materials containing the responsible pathogen or toxin. Additionally, pathogens and toxins exist in nature at suboutbreak thresholds. The most notable example is anthrax. While information on anthrax—including location, types of animals afflicted, and general information on the strain—is widely available in public libraries, obtaining a viable sample is not as easy. [62] A trained microbiologist would likely be needed to identify and isolate the mate-

rial. This skill set would not be available to an untrained individual nor would it be easily mastered by reading a textbook on the subject. Therefore, not only must the bioweaponeers be able to cultivate the sample from nature, but they must be able to overcome the hurdles of time and effort to sort through all of the strains of a particular pathogen found in nature in order to find a suitable choice.

Microbial culture collections—both domestic and foreign—are a second potential source of pathogens and toxins. Before the passage of the Antiterrorism and Effective Death Penalty Act in 1996, pathogen acquisition from microbial culture collections in the United States was not closely monitored. For example, the ATCC sold culture strains to Iraq in the 1980s. Many of these pathogens were attenuated, avirulent strains, and could not have been used directly as biological weapons; however, they could have provided valuable information for research and development programs. It should be noted that ATCC no longer ships "select agents" to any person or facility.

Foreign microbial collections present a greater potential for acquisition. ATCC estimates that as many as 450 culture collection centers exist worldwide.[63] Some of these facilities belong to larger networks. For example, the United Nations Educational, Scientific, and Cultural Organization supports the Microbiological Resource Centers Network. The network comprises 31 cultural collection centers in 25 nations.[64] These facilities require some type of evidence that the person requesting a sample is, in fact, a legitimate researcher and is associated with a credible facility. Although certification of proper credentials is now standard in the United States, an individual who is legitimately employed at a bioscience facility could still acquire a pathogen or toxin for nefarious purposes. International standards to control the acquisition of pathogens from culture collections do not currently exist.[65]

Legitimate bioscience laboratories constitute a third potential source of BW materials. Such laboratories, which are located around the world to meet critical public health functions, house and conduct research on dangerous biological agents that could be vulnerable to theft. The United States and other countries have recognized this fact and have begun implementing laboratory biosecurity standards at microbiological research facilities—the United States has done so both domestically and abroad. For example, the USA PATRIOT Act of 2001 and the Biological Preparedness and Response Act of 2002 mandate heightened security for facilities in the United States that house certain biological agents determined to be a threat to public or agricultural health. Abroad, the U.S. Cooperative Threat Reduction program is currently implementing security at many of the facilities that were associated with the Soviet Union's BW program. Although these efforts may reduce the risk that dangerous biological materials will be diverted for weapons proliferation, international standards for laboratory biosecurity do not currently exist.[66]

Production of the Agent in Suitable Form and Quantity

Having acquired a pathogen or toxin, a would-be bioterrorist needs to consider how much material is necessary for reliable infectivity after dissemination. Therefore, to increase the likelihood of success, the would-be bioterrorist must be able to calculate how much material is required to injure or kill the desired number of individuals. Moreover, such calculations need to factor in the anticipated die-off rate for the pathogen (i.e., how many organisms would likely succumb to environmental stressors during dissemination), as well as to predict how much of the organism would likely come into contact with members of the target population.

Increasing the quantity of a pathogen is a multiple-step process. Following the acquisition of a seed culture, a bioterrorist technician would have to inject it into a flask or fermenter that contains appropriate growth medium. Different types of pathogens and toxins require different media in which to multiply. While most bacteriological agents can propagate outside of a host, viral agents cannot; consequently, viruses require additional, sometimes highly sophisticated, treatments to stimulate growth. In general, the necessary growth media, supplies, and equipment are all easy to acquire and many of these items may be obtained in prepackaged kits. Since agents are always susceptible to environmental degradation, special precautions must be taken to preserve the integrity of the agents during this amplification process. Additionally, it is critical that the technician be able to assess whether agents are weakened during amplification by contaminants or genetic mutations.[67]

In addition to amplification, effective dissemination of most material requires that it be processed to resist environmental stressors, to survive dissemination, and to have increased infectivity and/or pathogenicity. While all pathogens and toxins are susceptible to environmental degradation, the stressors to which they are susceptible vary. For example, viral agents in general are more susceptible to ultraviolet light than are bacterial agents. Consequently, in order to process a pathogen or toxin for eventual use as a biological weapon, the technician must understand the environmental susceptibilities of the particular material identified for use.

Manipulating the material to increase its survival rate during dissemination requires expertise in both the particular pathogen or toxin and its dissemination. Not all dissemination methods are viable for every pathogen and toxin. Anthrax is generally not susceptible to most environmental stressors; however, in order to have the most effective impact on a target population, it should be processed to a small enough sporulate that it can be easily inhaled and become lodged in the victim's respiratory tract. This particular type of skill requires knowledge and experience in aerosol technology. Successful dissemination would also be aided by experience in overcoming electrostatic attraction to prevent clumping, and in microencapsulation of the agent to decrease its environmental susceptibility. It

should be noted, though, that not all biological agents require production and processing to be a dangerous biological weapon. Even in their natural and unprocessed forms, contagious agents such as smallpox and foot-and-mouth disease (FMD) have the potential to cause severe casualties and disruption.

The level of processing an agent requires depends not only on the particular biological agent, but also on the state of the agent. Liquid agents are relatively easy to produce. The only processing required after amplification of a liquid agent might include the addition of stabilizers. The creation of dry agents requires the produced material to be either spray-dried or freeze-dried (lyophilized) and then milled to achieve the optimal particle size for inducing pulmonary infections. As preeminent former U.S. bioweaponeer William Patrick recognized, liquid agents are easy to produce but are more difficult to disseminate successfully, while dry agents are more difficult to produce but relatively easy to disseminate.[68] Both dry and liquid agents are suitable for crude dissemination, and both can be aerosolized. Dry agents are typically more robust and more likely to survive the aerosolization process than are liquid agents.

Finally, processing material to increase a pathogen's or toxin's infectivity and/or pathogenicity requires a highly specialized expertise that combines knowledge of a particular pathogen or toxin with knowledge of genetics and DNA processes. In order to increase aspects of a pathogen's or toxin's DNA profile, an individual would need to know what particular part of the DNA strand needs to be modified and how to modify it. This may involve the use of specialized equipment, such as a DNA splicer, which likely would be available only to well-funded organizations and useful only to experts in microbiology. However, if the correct strain of a pathogen is selected, such genetic engineering is not necessary for the development of a successful biological weapon.

Effective Deployment of the Agent

Dissemination is the process of spreading a pathogen or toxin to cause infection. Similar to natural outbreaks of disease, intentional outbreaks rely on three pathways for infection: inhalation, ingestion, or percutaneous inoculation. Methods for dissemination range from crude to sophisticated. The two successful bioterrorist attacks in the United States both used crude dissemination methods. In the first case, the Rajneeshee cult simply placed samples of *Salmonella* on salad bars. In the second case, an unknown actor or actors mailed weaponized anthrax in envelopes.

Experts generally agree that inhalation infection requires far fewer organisms than ingestion or percutaneous inoculation.[69] However, inhalation of a pathogen or toxin requires it to be aerosolized. Both liquid and dry agents can be aerosolized, but the mechanical stresses inherent in the aerosolization process of

liquid slurries can destroy most of the pathogen.[70] A biological weapon delivery system that relies on aerosolization would likely aim to disseminate particulates 10 microns or less in diameter, as particles 20 microns or larger are more likely to be filtered out by natural processes. Small particles also can remain airborne for longer periods of time than large particles can; however, a diameter of less than 0.5 microns tends to result in unstable particles that are more susceptible to environmental degradation.

Widespread disagreement appears in the literature regarding the possible success of a biological attack using low-technology methods for aerosol generation (e.g. handheld spray cans and truck-mounted sprayers).[71] However, a recent Canadian study showed that it is technologically feasible to disperse biological agents from agricultural sprayers (e.g. aircraft and backpack sprayers) by using formulations available from agriculture supply stores.[72] While most of the aerosol would be dispensed in the agriculturally useful size range of 100-150 microns, enough small droplets (2-7 microns) would be formed to penetrate houses and contaminate the nasal passages of residents. Experts disagree on how successful an attack could be that relies on a dissemination technique with a low yield of aerosolized particles within the optimal size range. Yet as the pharmaceutical industry actively researches and develops methods for the aerosol delivery of medical drugs, higher-technology methods will become more accessible. Over time, more individuals will likely have the knowledge and access to the equipment necessary for the aerosol delivery of pathogens.

A biological weapon also can be designed to cause infection through ingestion. This dissemination method would involve contaminating food, water, or medical supplies. This type of dissemination is similar to early BW use, and it is primarily a method of sabotage. The Ranjneeshee cult deployed its biological weapon—*Salmonella typhi*—to cause infection through ingestion. Some commentators have suggested that municipal water supplies are at high risk of contamination by a biological weapon.[73] But many BW experts have argued that filtration, chlorination, and dilution processes, combined with the large numbers of organisms required to cause infection through ingestion, make the contamination of municipal water systems a low-probability, low-consequence event.[74]

Another dissemination method, percutaneous inoculation, aims to infect by dermal exposure. While intact skin provides most hosts with adequate protection against most biological agents, damaged skin or mucous membranes are vulnerable to pathogen penetration.[75] Because large areas of damaged skin are rare, percutaneous inoculation usually results in limited, nonlethal exposure. The victims of cutaneous anthrax from the fall 2001 attacks in the United States, for example, were treated, and they successfully recovered from the disease. It is extremely unlikely that a biological weapon, disseminated to cause infection through percutaneous inoculation, could cause a high-casualty event.

Although the three primary routes of infection are inhalation, ingestion, and percutaneous inoculation, BW programs have also researched other types of dissemination methods, such as the use of vectors. A vector is another organism that carries a pathogen to a host. A small sample of known vectors includes fleas (plague), mosquitoes (yellow fever and malaria), and mice (hantavirus). It is theoretically possible to introduce a pathogen into a targeted population intentionally via an animal vector. However, this method would require an additional skill set, such as expertise in entomology.

Humans can also be used as vectors for dissemination, such as in the intentional infection of an unsuspecting victim or a willing collaborator with a contagious disease so that the infected person could then spread the disease to others. This method would be most effective with a disease such as influenza, which is transmissible during its prodromal (presymptomatic) stage, when an individual is contagious but does not show any symptoms. The case of the willing collaborator would likely cause higher casualties because he would avoid treatment, but neither of these methods of dissemination would likely result in mass casualties.

A bioterrorist could also use himself as a vector. For example, he could infect himself with variola major to contract smallpox, which he could attempt to spread to others. Although frightening as a possibility, this "smallpox martyr" scenario does not represent a high risk. Variola major is not readily available; smallpox has been eradicated from nature and its virus is stored in only two official repositories, the CDC in Atlanta and the State Center of Virology and Biotechnology in Russia. Moreover, smallpox is generally not contagious during the prodromal stage. Because variola major virus is not highly contagious, dissemination by a smallpox martyr would not result in mass casualties.[76]

However, some diseases transmitted by a human vector could represent a higher risk. For example, foot-and-mouth disease, which is highly contagious and lethal in cloven-hoofed animals, is endemic in much of the world. A human could unintentionally transmit it to susceptible animals via contaminated clothing or shoes. Since FMD is not endemic in the United States and an outbreak of it in the United States would result in the culling of perhaps thousands of animals, FMD is considered one of the greatest potential threats to the U.S. beef and pork economies.[77] FMD also represents a significant bioterrorist threat. It would not be particularly difficult for a terrorist to travel to an FMD epidemic location, perhaps India or China, obtain a scab from an infected animal, and incubate the virus by infecting a pig (swine are notorious for producing and excreting a large amount of virus into the air). The terrorist could either act as a vector for the disease by contaminating his own clothing, or he could disseminate the agent directly with mucus from the infected pig. Either method of introducing FMD into an animal population in a region of the world where FMD is exotic could be effective. And the more places a terrorist disseminated the virus, the more devastating the consequences could be.[78]

Once a biological weapon is dispersed, weather conditions play an important role in distributing the agent, especially in the case of aerosolized agents. Weather conditions may help or hinder the agent's effective dissemination and viability, depending on relative humidity, temperature, altitude, sunlight, wind, and the inversion layer. Additionally, each agent has its own environmental susceptibilities and sensitivities. Consequently, knowledge of one pathogen and its susceptibility to environmental stressors does not necessarily translate into knowledge of the environmental hardiness of other pathogens.[79]

Deployment of a pathogen or toxin in a closed environment, such as a subway system or building, escapes some of the meteorological issues but faces a different set of possible problems. For an optimal indoor deployment, a would-be bioterrorist would need to have extensive knowledge of forced-, or closed-air systems and information about the specific type of system that the target facility uses, including possible filtration systems, air-flow patterns, and maintenance schedules.

Summary of Technical Hurdles

This review of acquisition, production, and deployment demonstrates that significant financial resources and technical sophistication are required to develop and deploy a biological weapon that could cause a high-consequence event. The historical record shows that states and well-funded, scientifically competent terrorist groups have encountered difficulties in one or more of the steps for BW production and use.[80]

In particular, obtaining a pathogen or toxin does not ensure production of a biological weapon that will produce a high-consequence event. First of all, if an avirulent strain of a pathogen is chosen, no significant outbreak of disease will occur.[81] Even after the right strain is selected, additional challenges face the bioterrorist, including isolation, amplification, protection against environmental degradation, and development of an effective dissemination method.

Most pathogens and toxins are not dermally active. Therefore, to cause incapacitation or death, these agents must enter a susceptible host either through ingestion or inhalation. Since most pathogens and toxins would not survive human digestive processes, aerosolization of agents for inhalation has been acknowledged to be the most effective method for achieving a mass-casualty biological attack.[82] Thus, the perpetrator needs to master the skills to optimize particle size and to decrease degradation from environmental stressors.[83] The perpetrator must then be able to select and use an appropriate delivery system. In general, these steps require moderate to high levels of scientific expertise and moderate to high levels of financial resources.[84]

Thus, well-developed states are judged to have the technical sophistication and financial resources to cause a high-consequence biological weapon event.

Less-developed states, which include nations currently identified as rogue states, generally do not have the technical sophistication and financial resources that well-developed states have and are assessed to be capable of causing BW events with moderate consequences. Bioterrorists, who generally lack the technical skills and financial resources of states, are currently considered capable of perpetrating low to moderate consequences with biological weapons.

Even a low-consequence event requires a considerable level of expertise to execute. In addition, the objectives of the perpetrators may be more easily realized by other means, such as conventional weapons. However, certain types of low-consequence events may be more likely than others because they require little organization, funding, or expertise. Because these acts are generally carried out by one or a few individuals, they are less likely to be detected or prevented. These "biocrimes" are generally targeted attacks, such as assassinations or murders. Although biocrimes are omitted from this study's discussion of nonstate actors because they do not constitute terrorist acts, they are nonetheless worthy of note. These attacks require a very low level of organization and expertise and, to date, have involved a limited class of agents, such as botulinum toxin and ricin. However, they may also include nonlethal agents. Because biocrime attacks can be carried out by a lone actor with a moderate level of technical expertise, they are considered fairly probable. However the consequences would be minimal, resulting in a single death or temporary illness. Generally, biocrimes cannot inflict mass casualties or the other forms of damage that designate an event as high consequence. Although biocrimes have a high probability of occurring, by definition biocrimes are limited to low consequences. From the BW perspective, biocrimes are low risk.

Finally, although a discussion of the technical hurdles is important, we must recognize that a bioterrorist need not face all of these challenges. If the would-be bioterrorists obtained an isolated and cultured agent from a research facility, they would not need to invest as many resources to produce an effective biological weapon. While this advantage is by no means insignificant, the bioterrorist may still need to process and/or deploy the BW material. The need for processing depends on the nature of the agent; an agent such as the FMD virus would require very little processing.

While the technical hurdles for weaponizing biological agents will remain constant, advances in and increased availability of biotechnology will enhance the capabilities of both states and nonstate actors over time.[85] Advances in technology will diminish the barriers to all three components: acquisition, production, and deployment. Research publications, patents, and Internet-based surveillance and reporting of disease outbreaks provide increasing amounts of information to identify specific facilities or regions where the virulent agent of choice may be obtained. Over time, more individuals will acquire the skills and technologies to create dangerous pathogens through chemical synthesis and ge-

netic engineering. And the cost to acquire these skills and technologies will gradually decrease over time.

In addition to providing increasing sources of pathogens and toxins, the growing global biotechnology industry will expand the amount of information, materials, and equipment potentially relevant to biological weapons, as well as the number of individuals with training in the life sciences. Recipes for isolating agents, making media, and growing cultures are available on the Internet, and their prevalence will increase as the biotechnology industry grows. In other words, advancing biotechnologies will allow increasingly more people, with less and less training, to master the various production skills.

Technology is also decreasing the technical challenges of both crude and sophisticated dissemination methods. Pharmaceutical companies continue to advance the science of processing organisms to withstand environmental stressors and effective aerosol delivery. Commercially available agricultural aerosol sprayers are also becoming more sophisticated. Finally, global travel is becoming increasingly easy and efficient, enhancing the opportunity for an infected martyr to spread disease. Although advances in biotechnology and the information age will improve scientists' abilities to combat outbreaks of infectious disease, these advances will simultaneously provide would-be bioterrorists with more opportunities for malicious introduction of infectious disease.

CONCLUSIONS

Although many states have the capacity to cause a high-consequence event, this outcome is unlikely because biological weapons have not proved to be reliable strategic weapons. Thus, it is considered low risk that well-developed states will use biological weapons (high consequences but very low probability). Although rogue states are the most likely state BW perpetrators, most can probably be deterred by threat of retaliation with other weapons of mass destruction or overwhelming conventional force. In general, rogue states lack the financial resources and technical sophistication available to well-developed states. Thus, the risk of rogue states using biological weapons is judged to be low to moderate (moderate consequences but low probability).

The major trend affecting the BW risk is a marked rise in terrorist activity. Many recent terrorist incidents have been carried out by highly organized and well-funded organizations. In contrast to terrorists of the past, these groups have shown a desire for mass casualties. Some of these organizations are well positioned to take advantage of several features of the BW landscape: the growing availability of both dangerous pathogens and toxins and BW-related expertise and technology. In addition, bioterrorists can exploit the numerous technological advances that have reduced the training and financial requirements of BW development. The risk of a nonstate actor's use of a biological weapon is currently

considered to be low to moderate (low-to-moderate consequences and low-to-moderate probability). However, the recent trend in terrorism—highly organized, well financed, and intent on mass casualties—as well as projected rapid advances in biotechnology suggest that the risk of nonstate use of biological weapons is increasing.

Table 3 summarizes the risk of the four different types of BW perpetrators described in this paper carrying out a BW event. The result of such an analysis allows for a prioritization of risks and mitigation efforts, leading to several policy recommendations. First, an intensive domestic focus on preventing and responding to low-sophistication biocrimes will not mitigate the higher-risk BW events. Second, although state-based arms control measures help set global norms, they do not address higher-risk events because rogue states will not participate in such arms control measures, and nonrogue states present a low risk. Third, unconventional BW nonproliferation strategies are necessary to make it increasingly difficult for sophisticated terrorist networks to obtain biological weapons. Simply preparing to respond to a bioterrorist event after it happens is not adequate.

Table 3
Various BW Risk Scenarios

Scenario	Probability	Consequences	Risk
Biocrimes (lone actors)	High, based on historical evidence	Very low by definition	Low
Biological warfare (well-developed states)	Very low, based on the historical record	High, based on technical sophistication of these states	Low
Biological warfare (rogue states)	Low, based on historical record	Moderate, based on technical sophistication of these states	Low to moderate
Bioterrorism (nonstate actors)	Low to moderate, based on historical evidence, but increasing	Low to moderate, based on the historical record and technical expertise, but increasing	Low to moderate, but increasing

In addition to its current focus on domestic biodefense, the United States should pursue international BW nonproliferation policies that aim to understand and protect the materials, technologies, and expertise that, although used for legitimate purposes, could be exploited to develop and deploy biological weapons. The ubiquity of these dual-use biological materials, technologies, and expertise compels the United States and other willing and able nations to provide support to those parts of the world where infectious disease outbreaks are common and where the bioscience and biotechnology industries are expanding. In addition, knowledge of the organizations that have considered perpetrating harm with biological weapons, and their motivations for doing so, must be improved.

However, efforts at controlling the biosciences must be pursued in a manner that avoids compromising basic biomedical and biodefense research. The best defense against the use of biological weapons will always be scientific research that develops improved vaccines, surveillance, diagnostics, and therapies that can mitigate the consequences of infectious disease outbreaks.[86]

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